

Gas und Eisriesen

Das Sonnensystem und seine nächsten Verwandten für
Nicht-Physiker

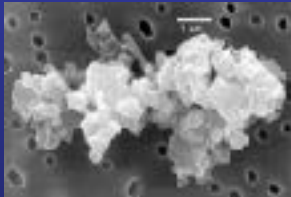
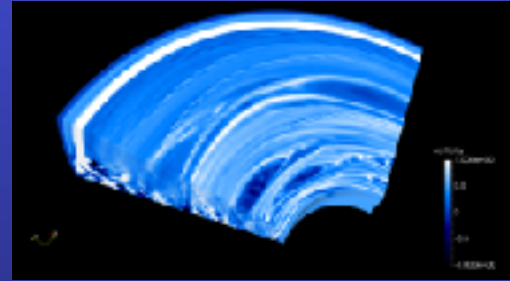
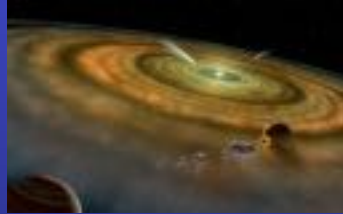
Hubert Klahr

mit Unterstützung von Jamila Miguel

Haus der Astronomie / Max-Planck-Institut für Astronomie

18.12.2018

Lecture Staub -> Planetesimale



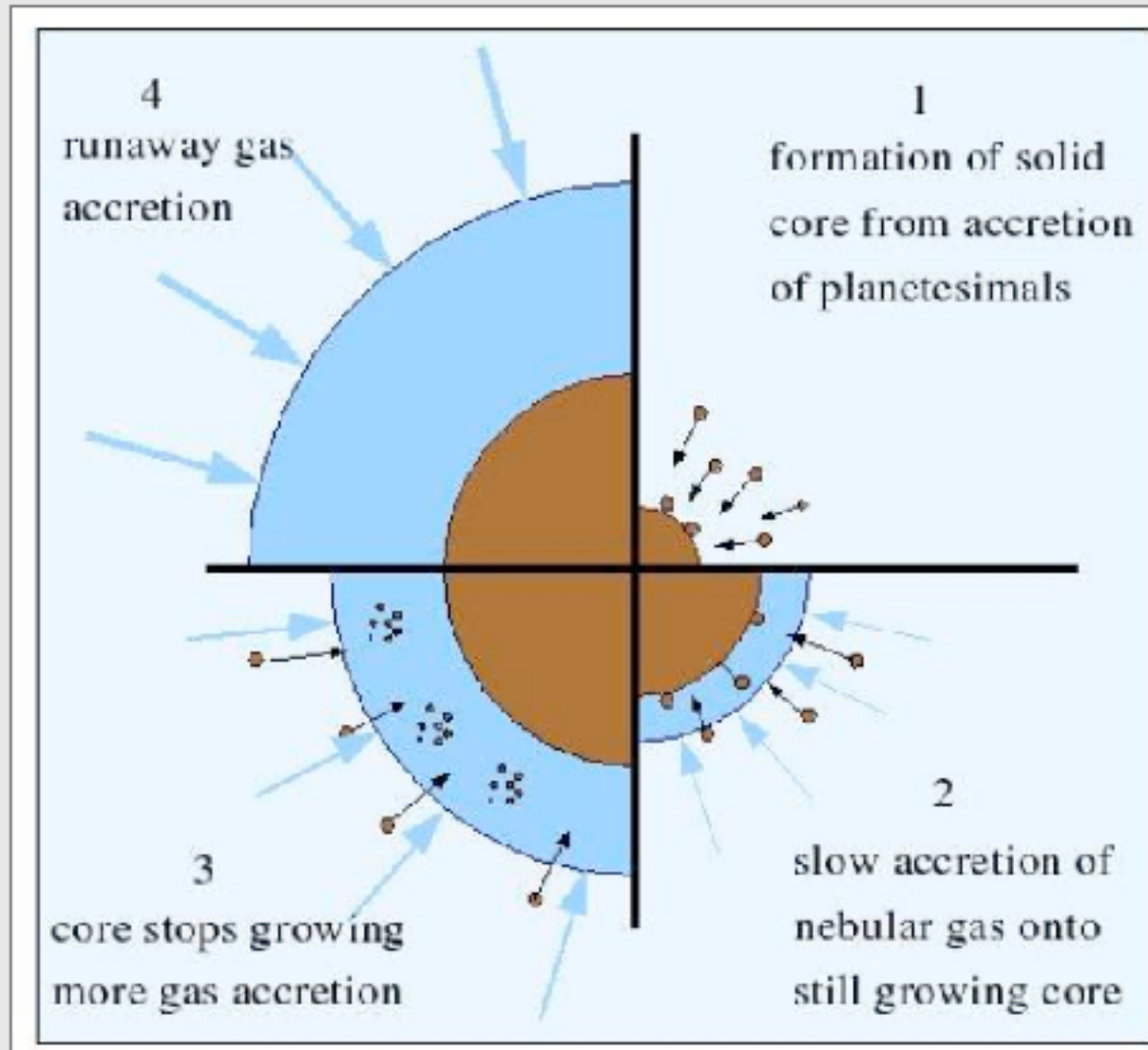
Wie baut man aus Staub und Eis Planeten?

10/04/2010

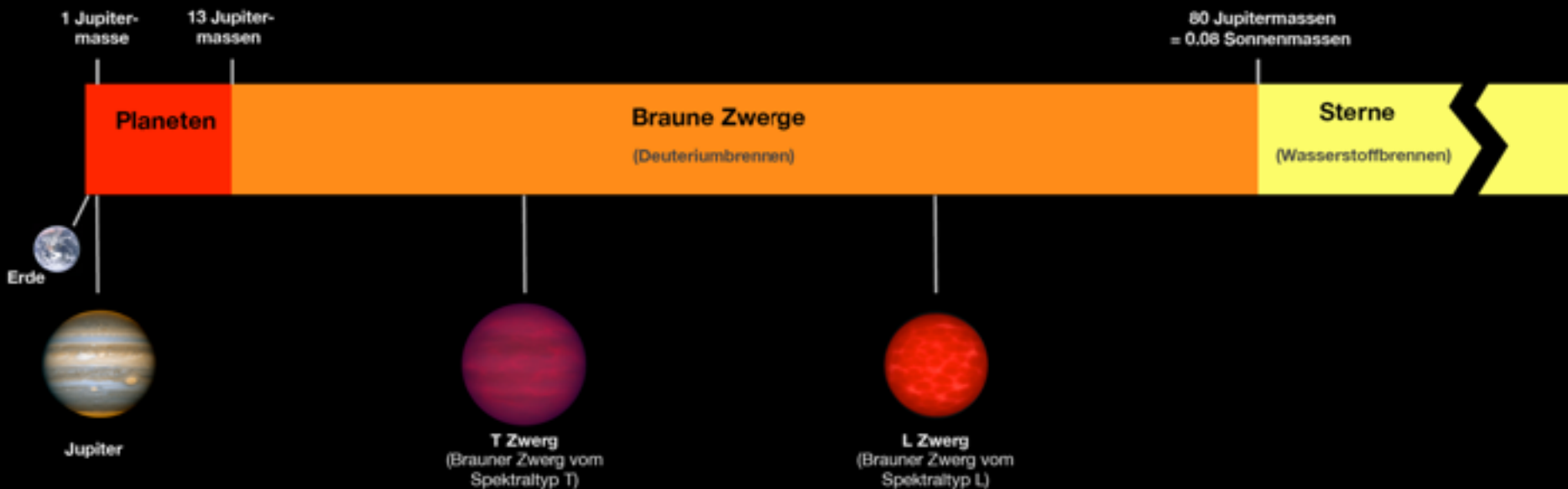
Hubert Klahr - Planet Formation -
MPIA Heidelberg

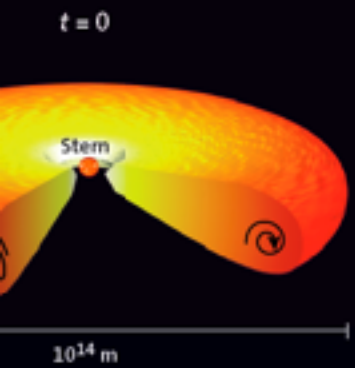


Giant planet formation: core accretion model

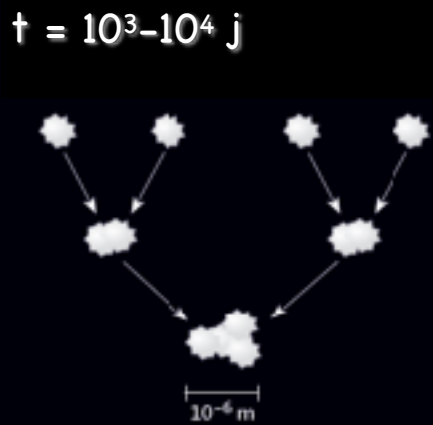


Was ist ein Planet? Definition über Masse ist willkürlich. Ein fließender Übergang zu den Sternen. Mögliche Unterscheidung über Entstehung? Planeten brauchen erst einen festen Kern und Sterne kondensieren direkt aus dem Gas aus? Leider keine Überprüfbarkeit am "lebenden" Objekt.

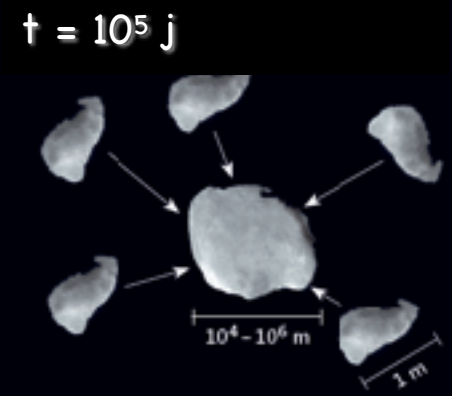




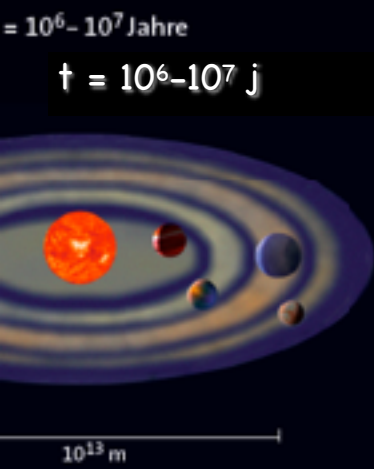
a. Turbulente Scheibe



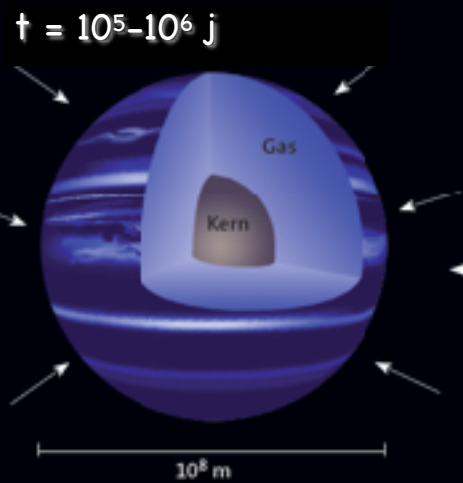
b. Stossen und Kleben



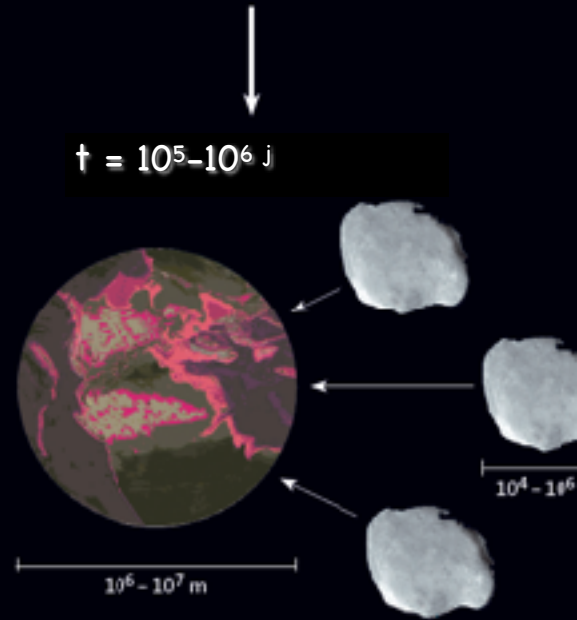
c. Gravoturbulente Fragmentation



f. Migration



e. Gasakkretion



d. Gravitation



Kant / Laplace: Entstehung aus einer Scheibe heraus.

Motivation

**Flug zu einem ent-
stehenden Gas-Riesen.**

Motivation

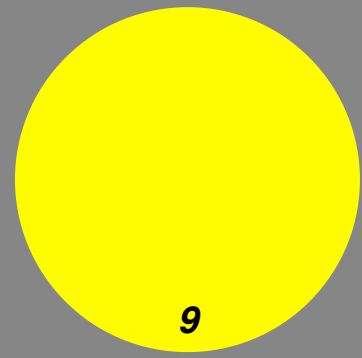
Jupiter:

Yamila Miguel
MPIA - May 2018

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*Jupiter der massereichste Planet
im Sonnen system*

*Jupiter als Schlüssel
zum Sonnensystem?*



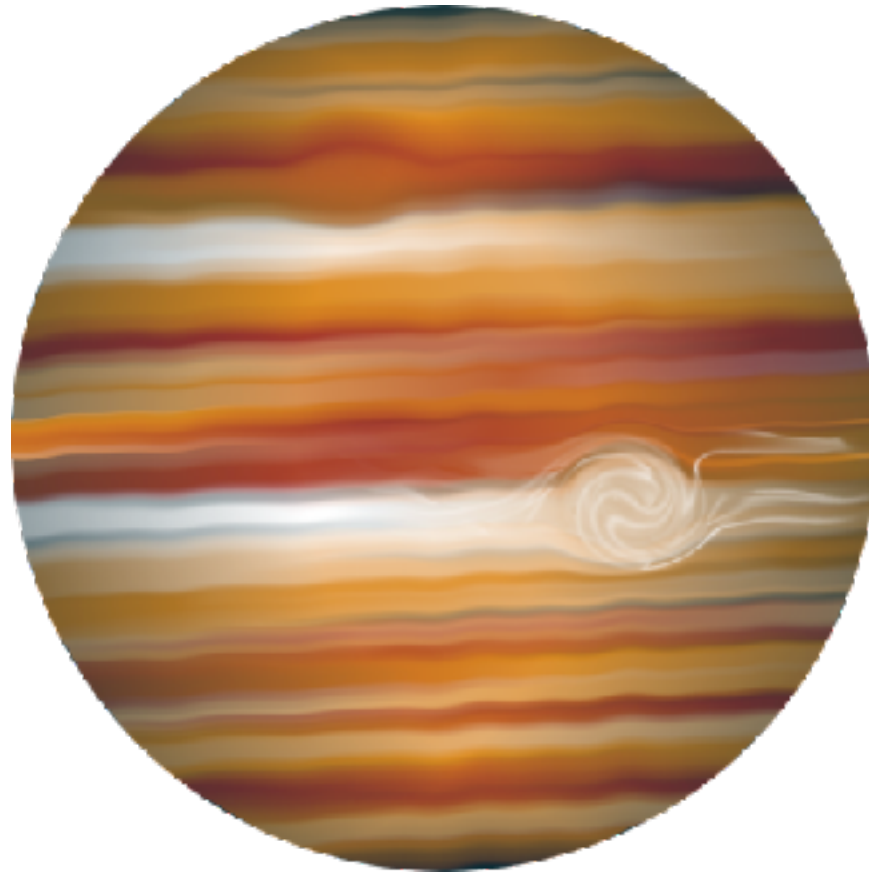
Wie ist Jupiters innere
Struktur?

Hat Jupiter einen
Kern?

Pre-Juno results

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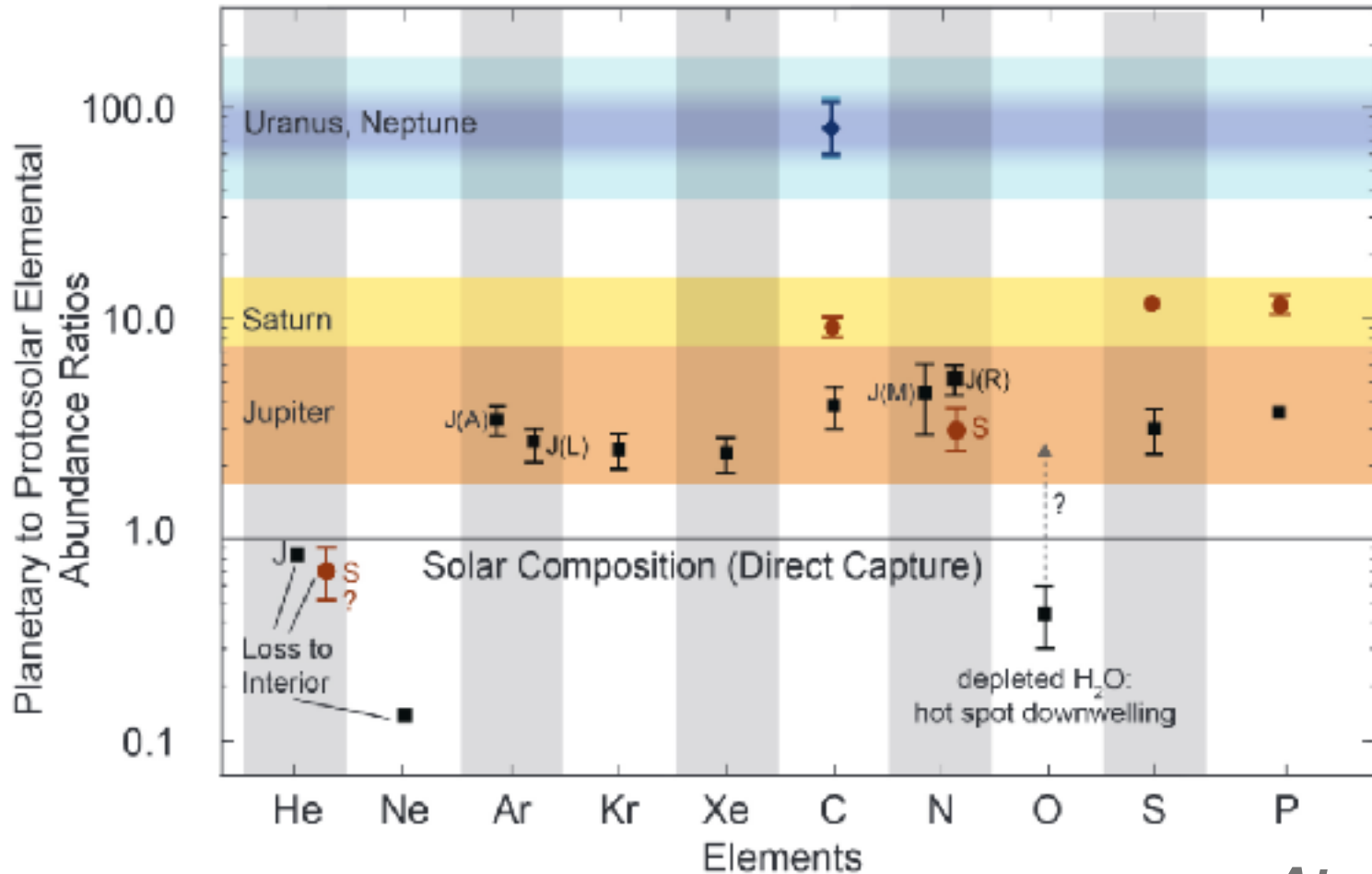


Pre-Juno Results

Jupiter's Atmosphere

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Atreya+2016

Pre-Juno Results

Jupiter's gravity field

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$$U(r, \theta) = \frac{GM}{r} \left\{ 1 - \sum_{i=1}^{\infty} \left(\frac{R_{\text{eq}}}{r} \right)^{2i} J_{2i} P_{2i}(\cos \theta) \right\}$$

$$J_{2i} = -\frac{1}{M R_{\text{eq}}^{2i}} \int \rho(r) r^{2i} P_{2i}(\cos \theta) d\tau$$

Even gravity

J_2 harmonics

J_4

J_6

J_8

J_{10}

0

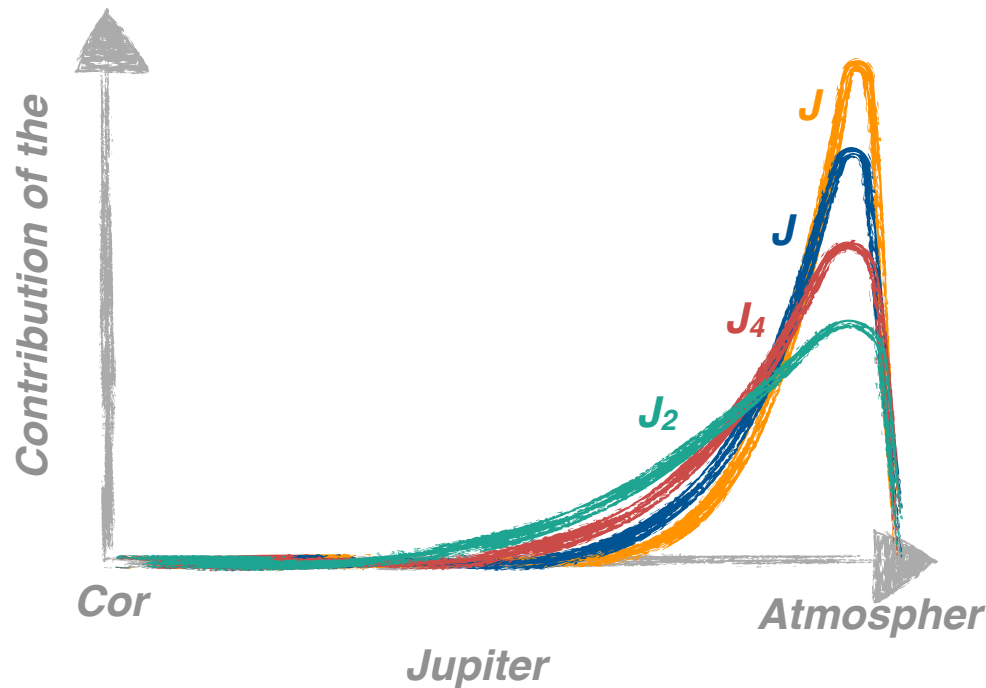
J_{22}

2 Static (rigid body)

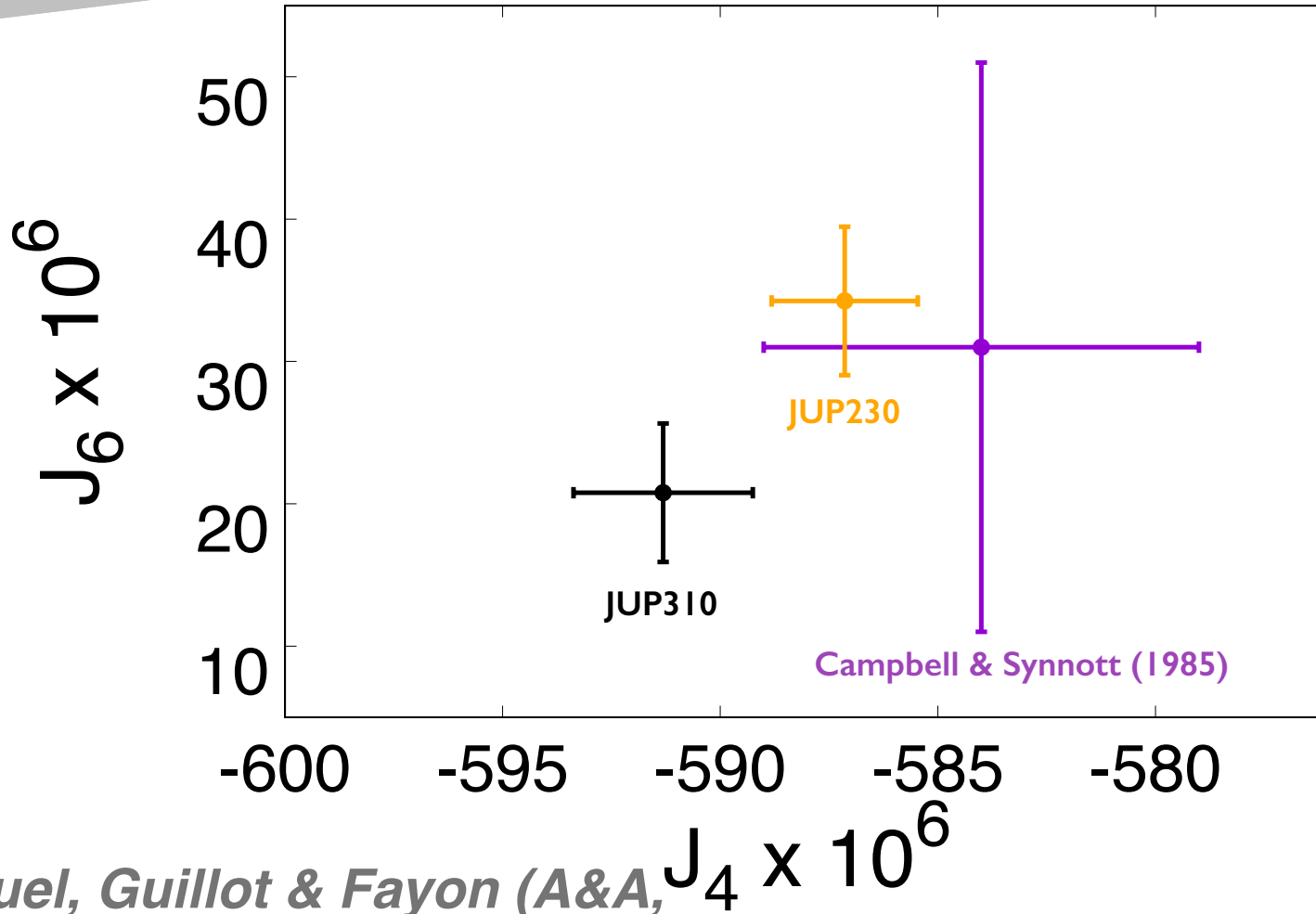
Dynamic (differential rotation)

Interior

Atmospheric dynamic



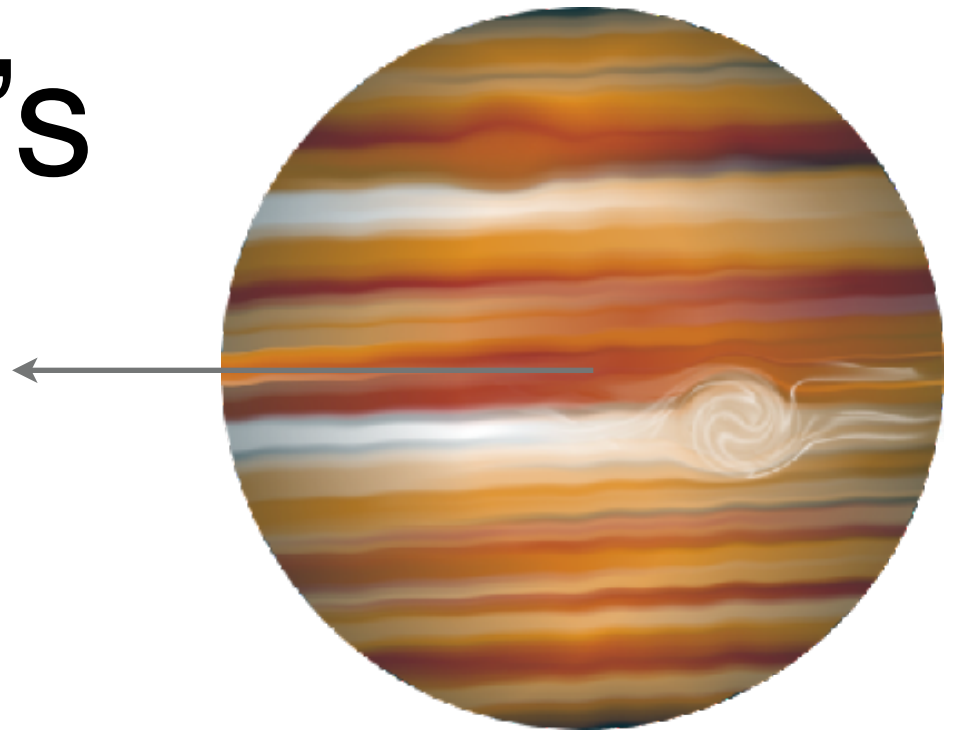
Jupiter's gravity harmonics



Miguel, Guillot & Fayon (A&A, 2016)

Jupiter's

$M_{\text{core}} = 0 - 17 M_{\text{Earth}}$
 M_z up to $40 M_{\text{Earth}}$
(e.g. Saumon & Guillot
2004,
Nettelmann + 2008, 2012,
Hubbard & Militzer, 2016,
Miguel + 2016)



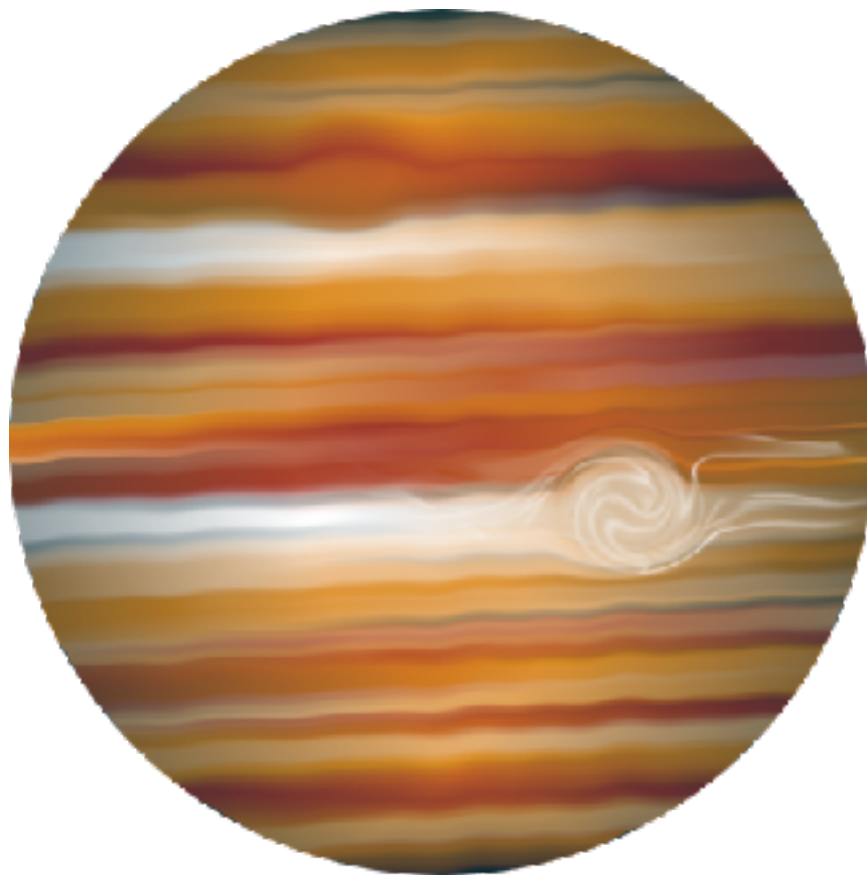
R, M, J₂, J₄, J₆,
Y, ...



Juno results

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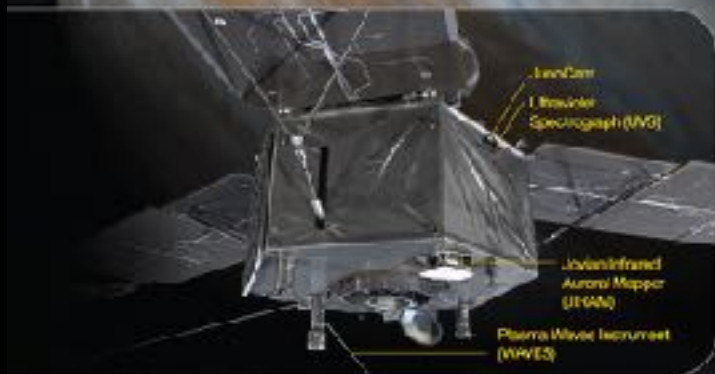


Juno mission: instru

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Juno Spacecraft



JunoCam
Ultraviolet Spectrograph (UVS)

Jovian Infrared Auroral Mapper (JIRAM)

Plasma Wave Instrument (PWI)

SPACECRAFT DIMENSIONS

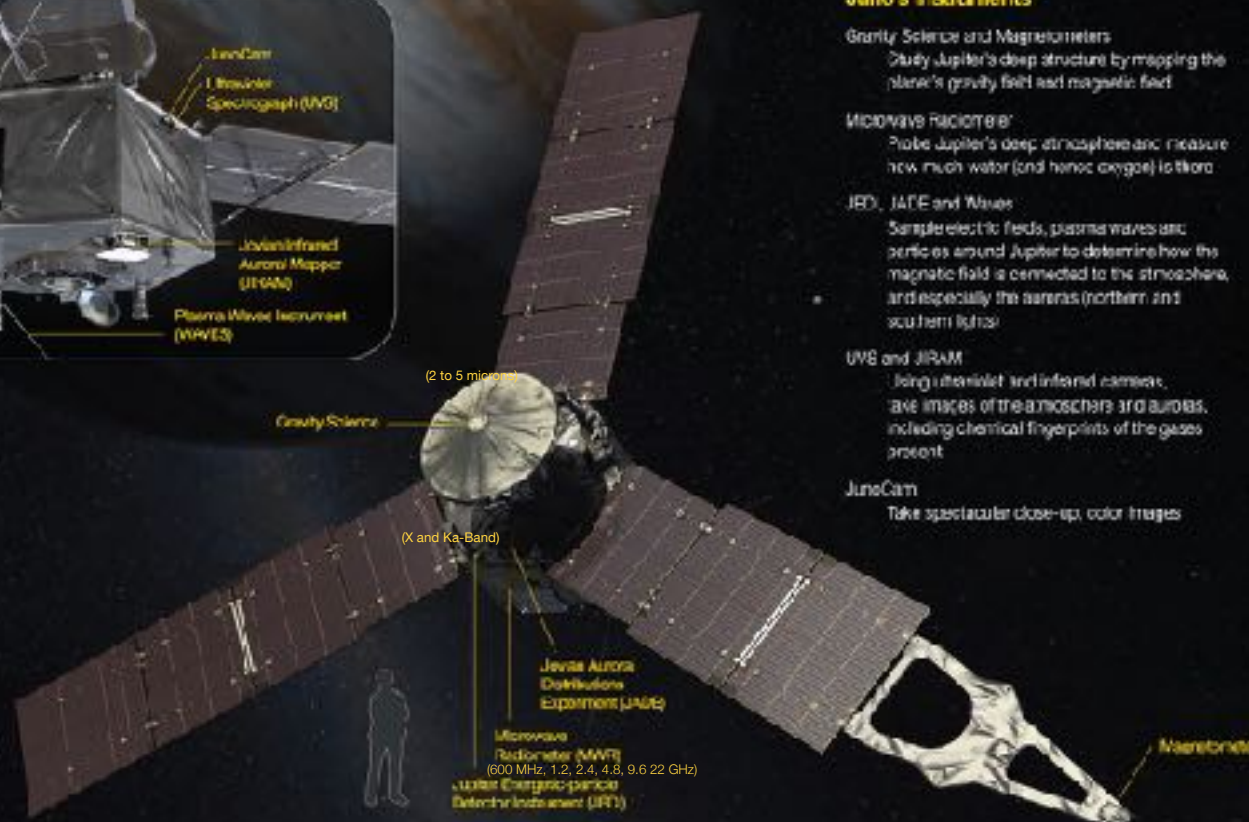
Diameter: 60 feet (20 meters)
Height: 15 feet (4.5 meters)

For more information:
mission.juno.swri.edu &
www.nasa.gov/juno

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov



(2 to 5 microns)

Gravity Science

(X and Ka-Band)

Jovian Auroral Distributions Experiment (JADE)

Microwave Radiometer (MRM)
(600 MHz, 1.2, 2.4, 4.8, 9.6-22 GHz)

Ultra-Compact Particle Detector Instrument (UCPD)

Magnetometer

Juno's Instruments

Gravity Science and Magnetometers

Study Jupiter's deep structure by mapping the planet's gravity field and magnetic field

Microwave Radiometer

Probe Jupiter's deep atmosphere and measure how much water (and hence oxygen) is there

JEDI, JADE and Waves

Sample electric fields, plasma waves and particles around Jupiter to determine how the magnetic field is connected to the atmosphere, and especially the auroras (northern and southern lights)

UVS and JIRAM

Bring ultraviolet and infrared cameras, take images of the atmosphere and auroras, including chemical fingerprints of the gases present

JunoCam

Take spectacular close-up, color images



Juno mission: photo

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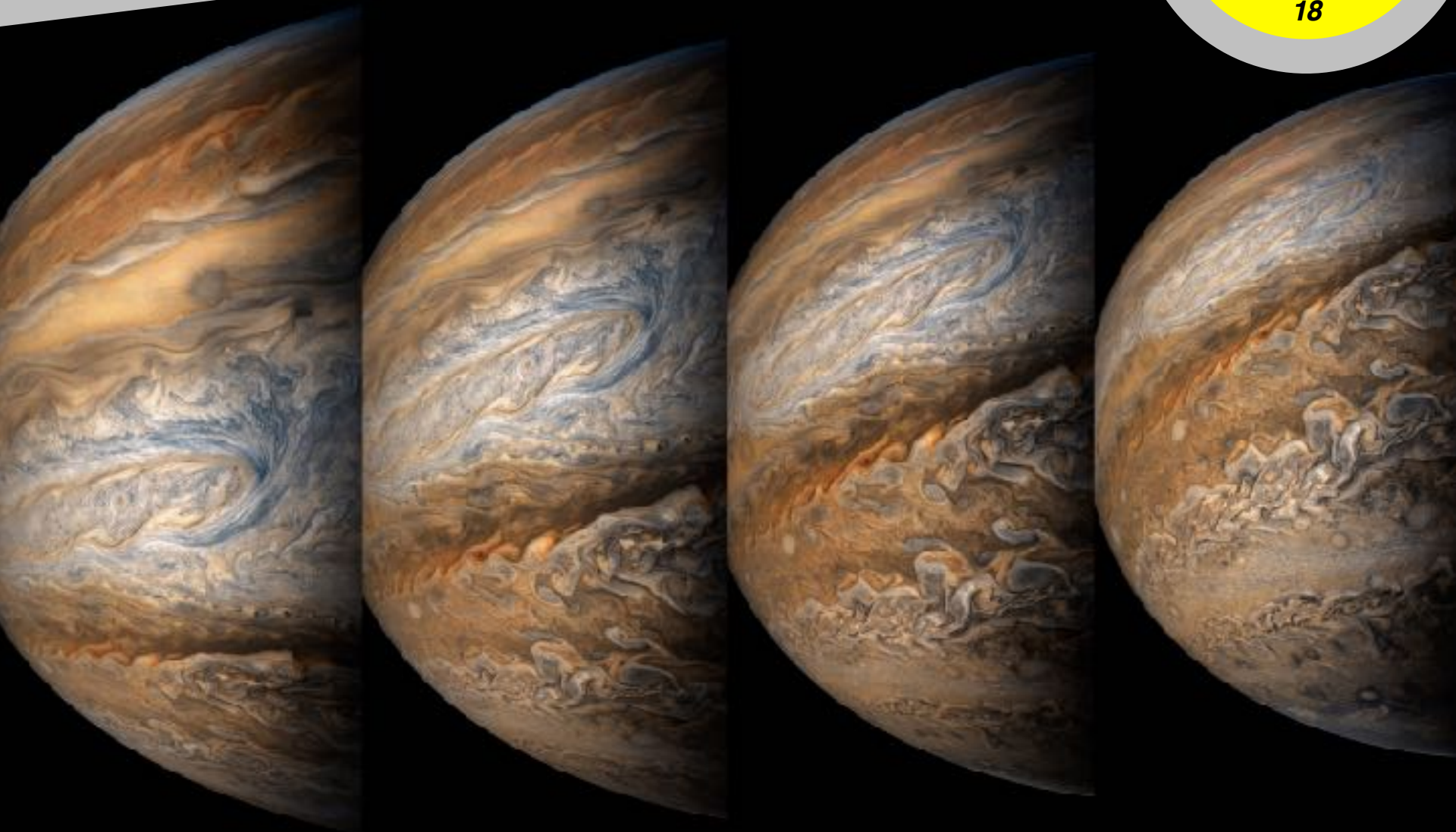




Juno mission: photo

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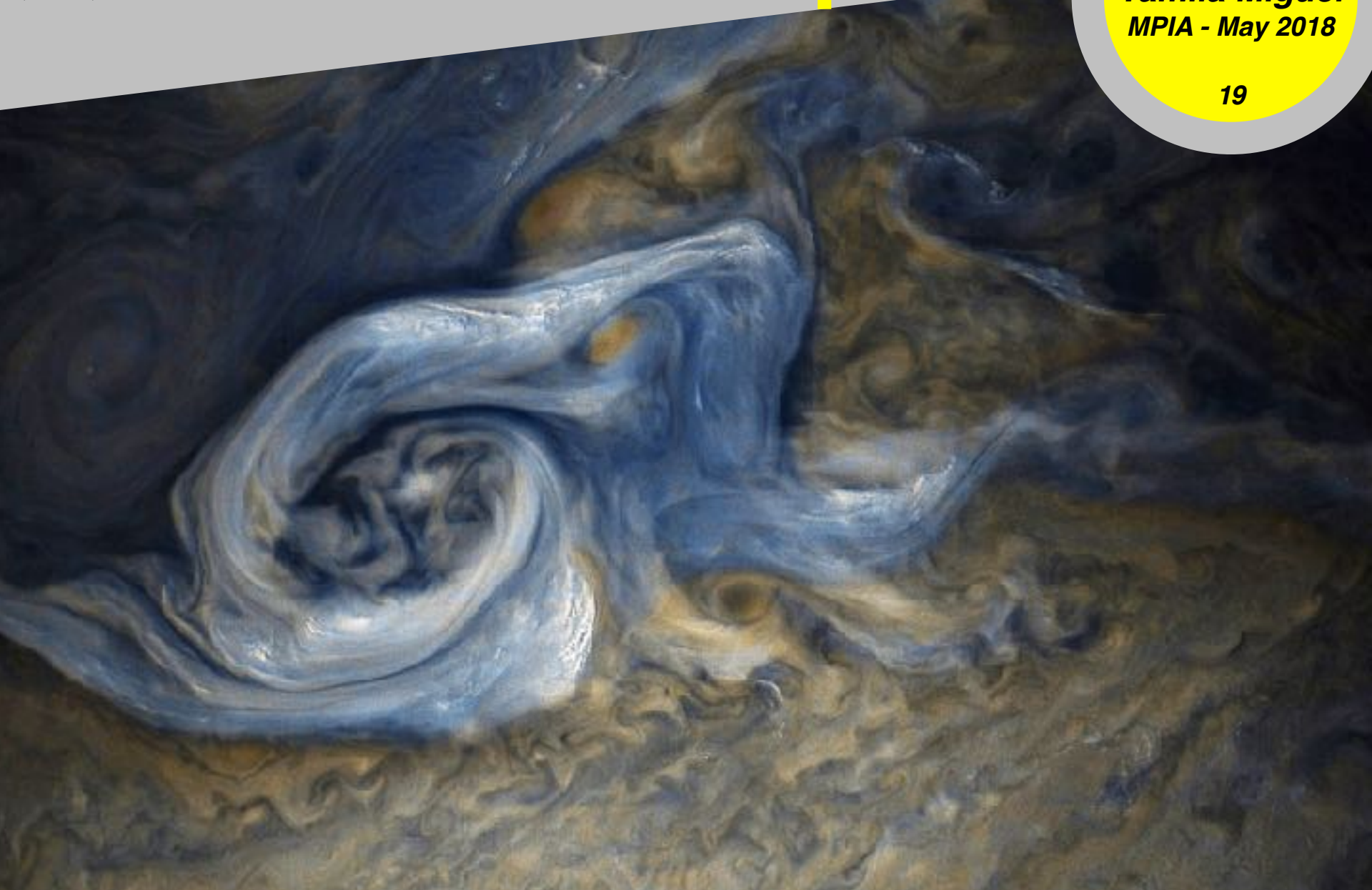




Juno mission: photo

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Juno mission: photo

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Juno mission: photo

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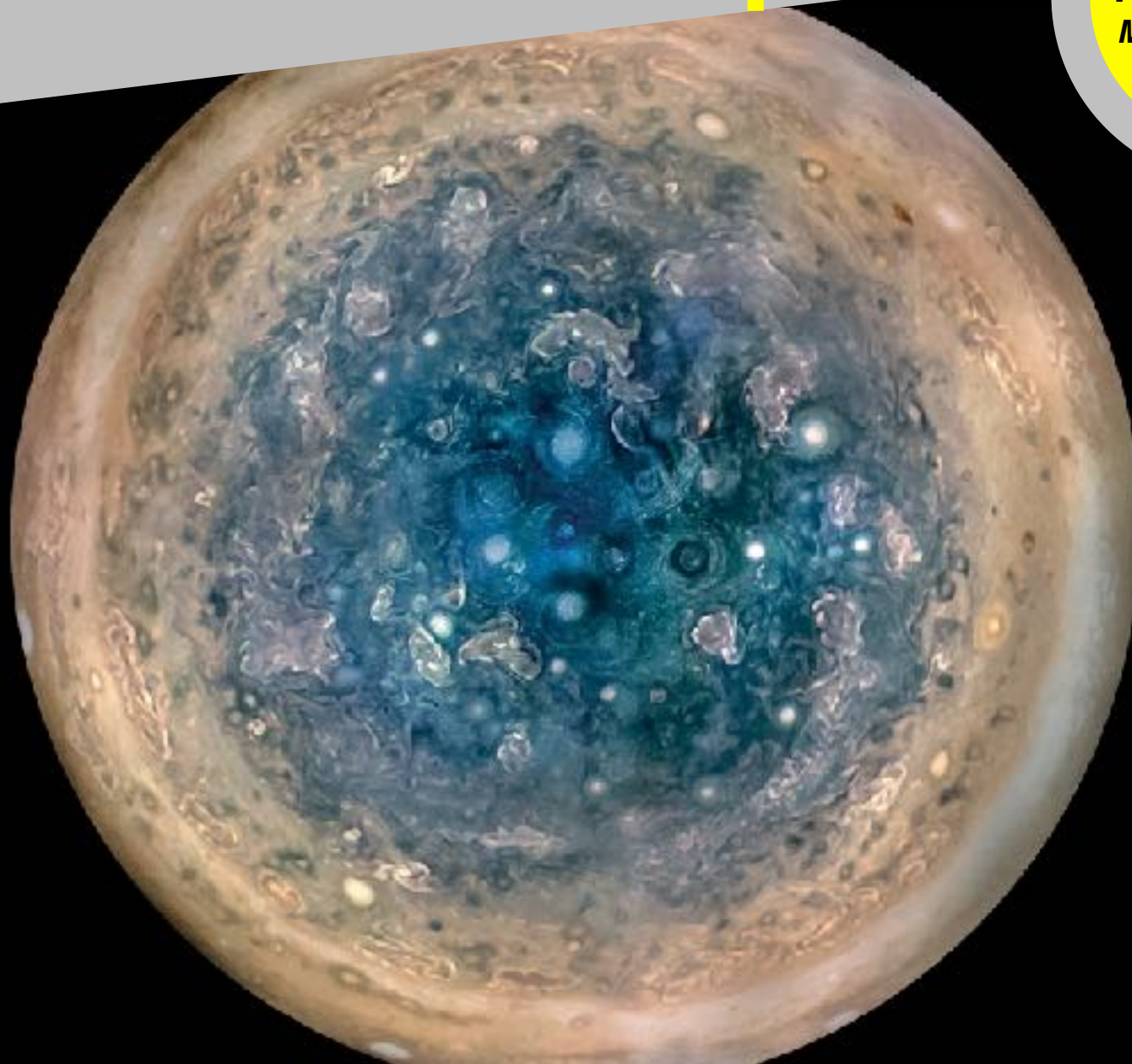




Juno mission: photo

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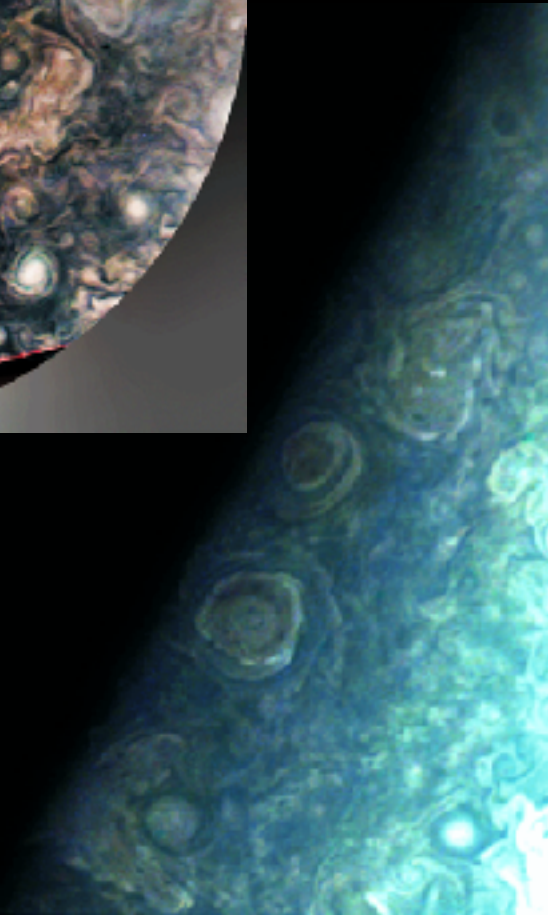
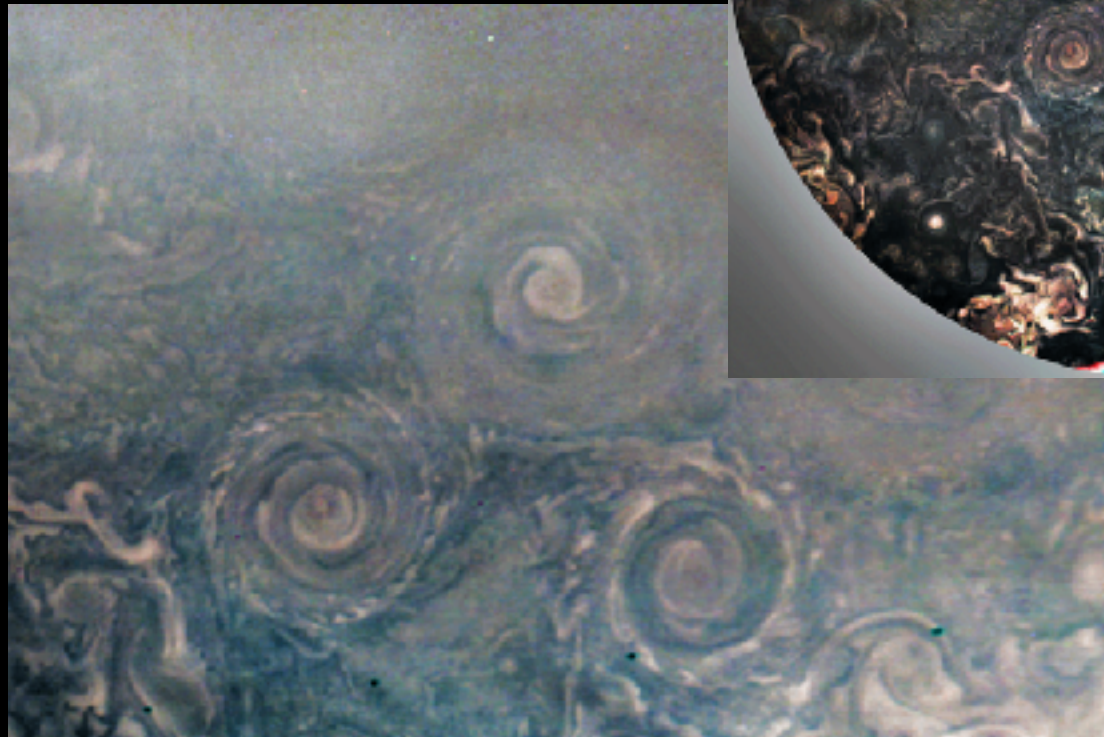
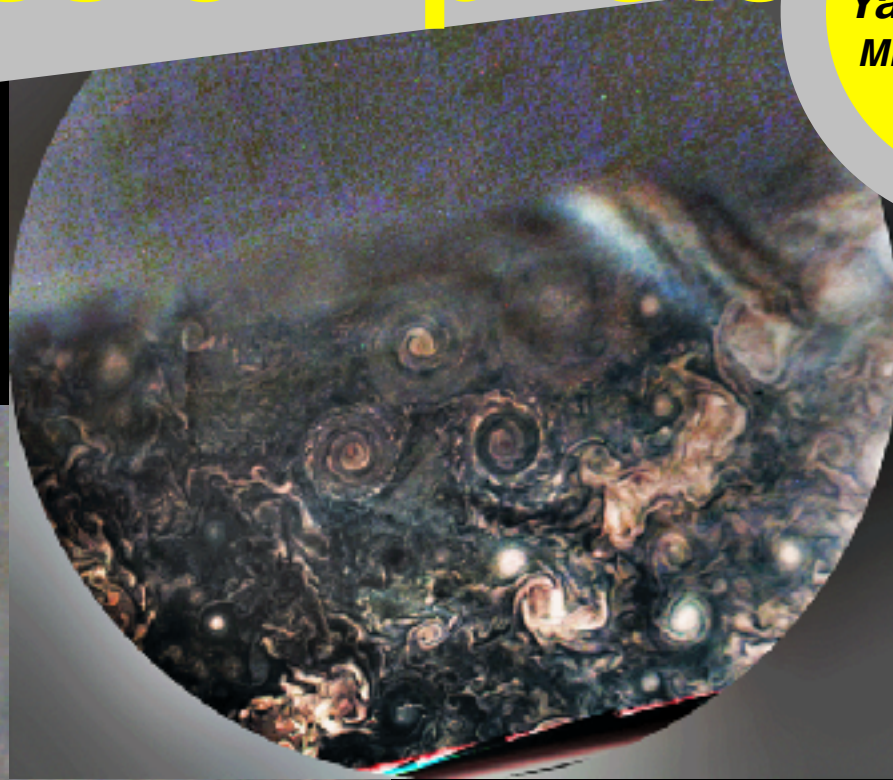




Juno mission: photo

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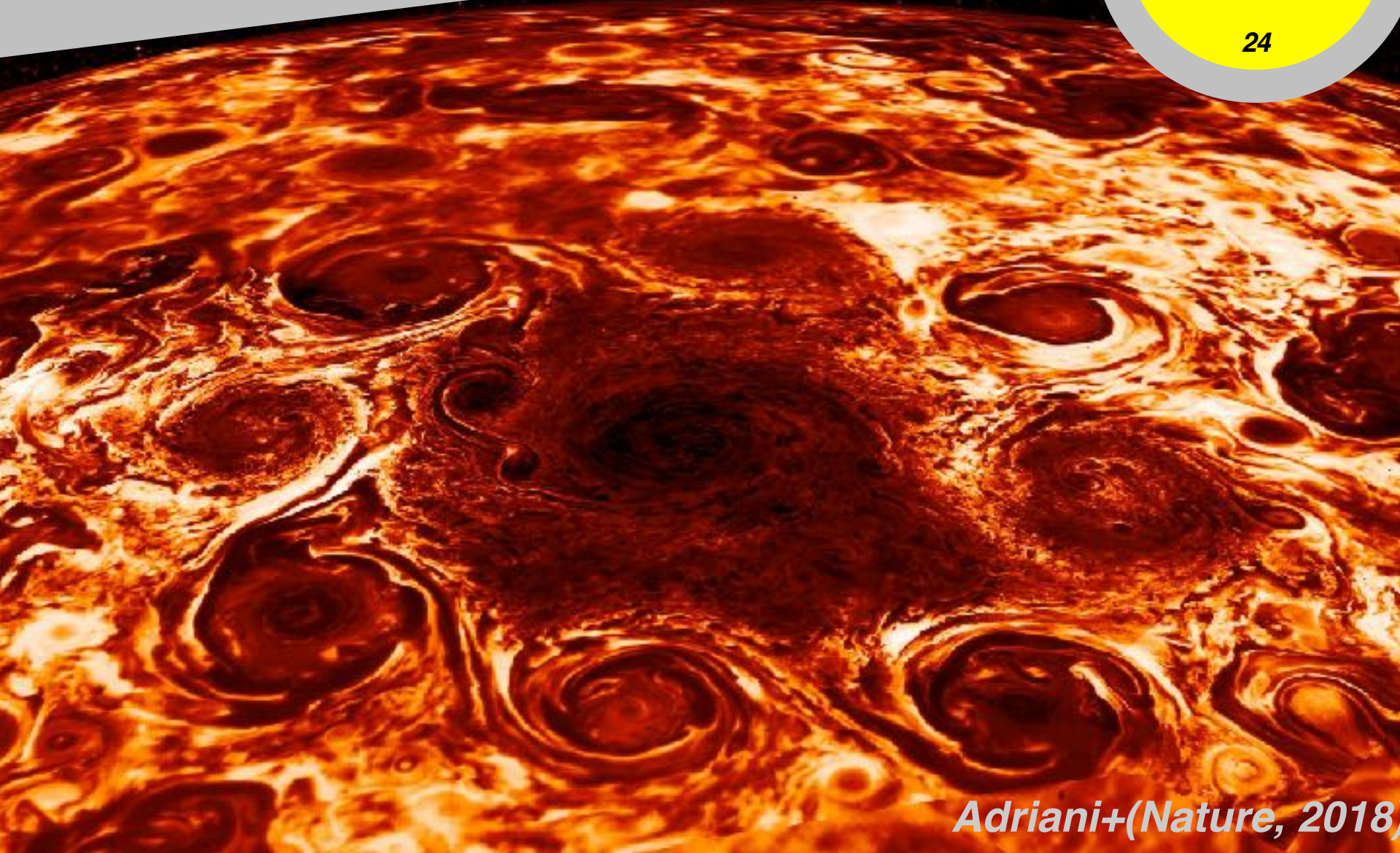




Juno mission: photo

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Adriani+(Nature, 2018)

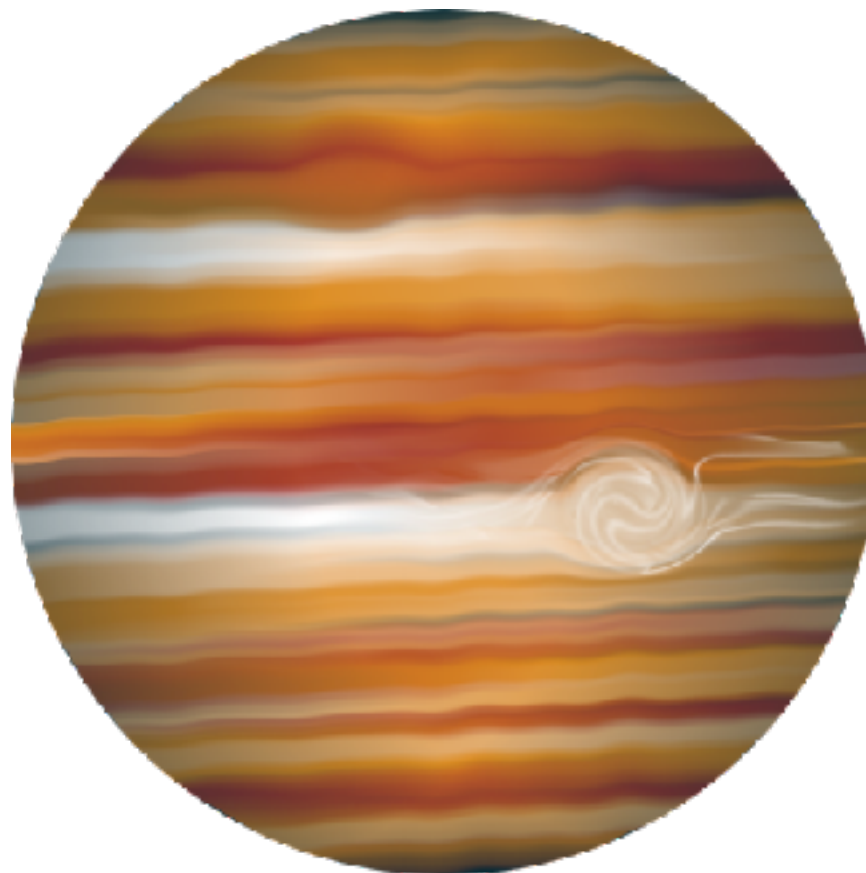


Juno results

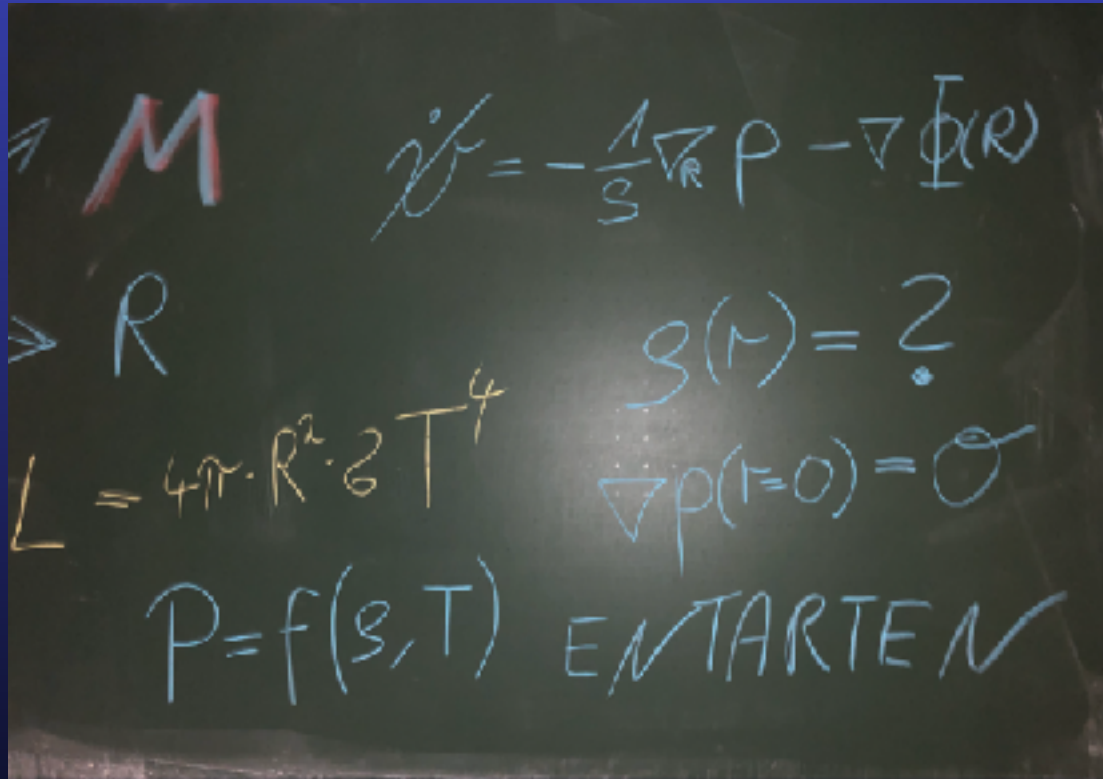
Gravity results

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Hydrostatisches Gleichgewicht: Druck Gradient kompensiert Gravitation -> vertikale Funktion für Dichte $\rho(r)$



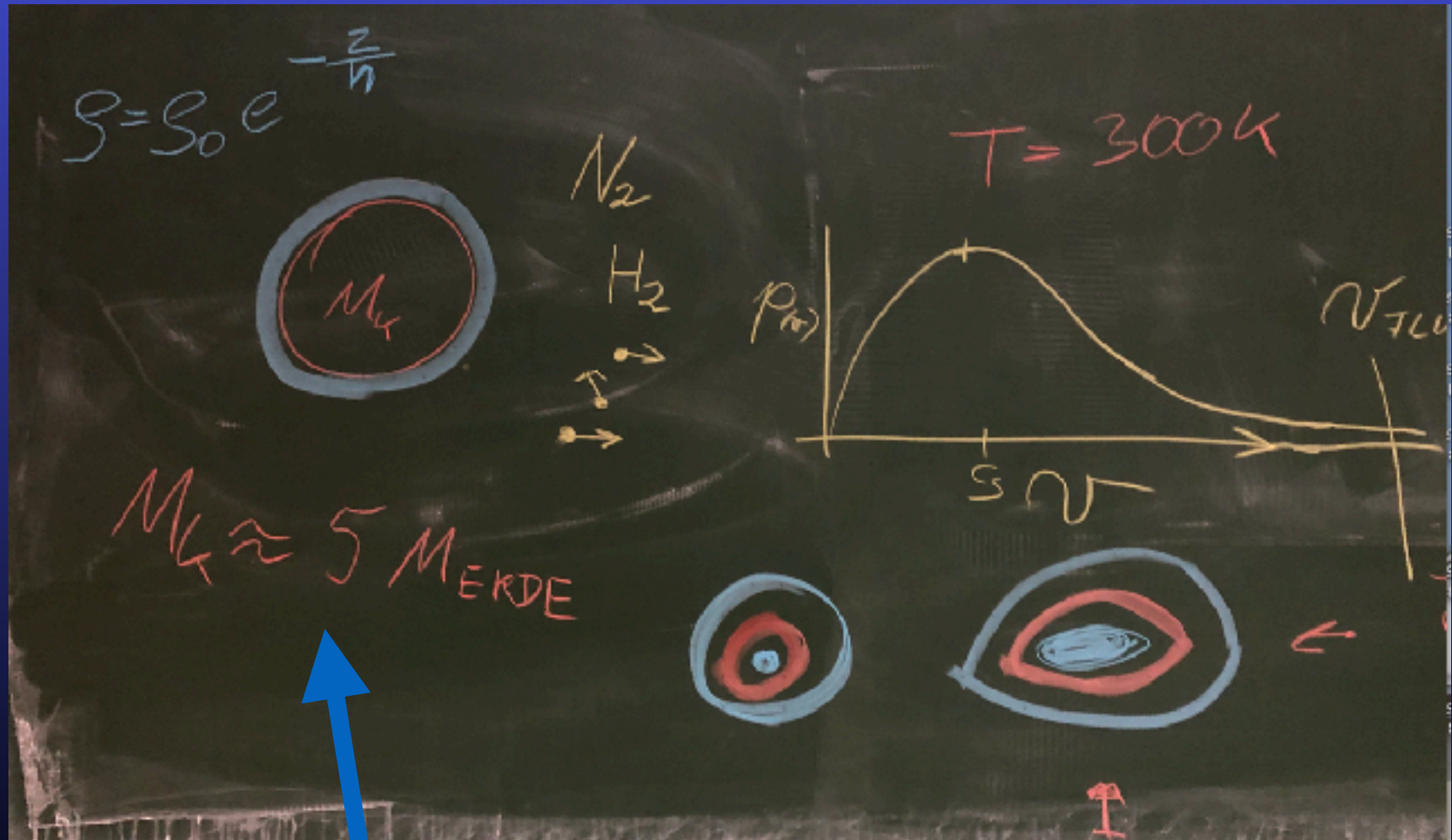
Handwritten equations on a chalkboard:

- $\vec{v} = -\frac{1}{\rho} \nabla p - \nabla \Phi(r)$
- $g(r) = ?$
- $L = 4\pi \cdot R^2 \cdot \sigma T^4$
- $\nabla p(r=0) = 0$
- $P = f(\rho, T)$ ENTARTEN

Gleichung wird mit Zustandsgleichung erst vollständig: Druck = Funktion von Chemischer Zusammensetzung, Dichte und Temperatur.

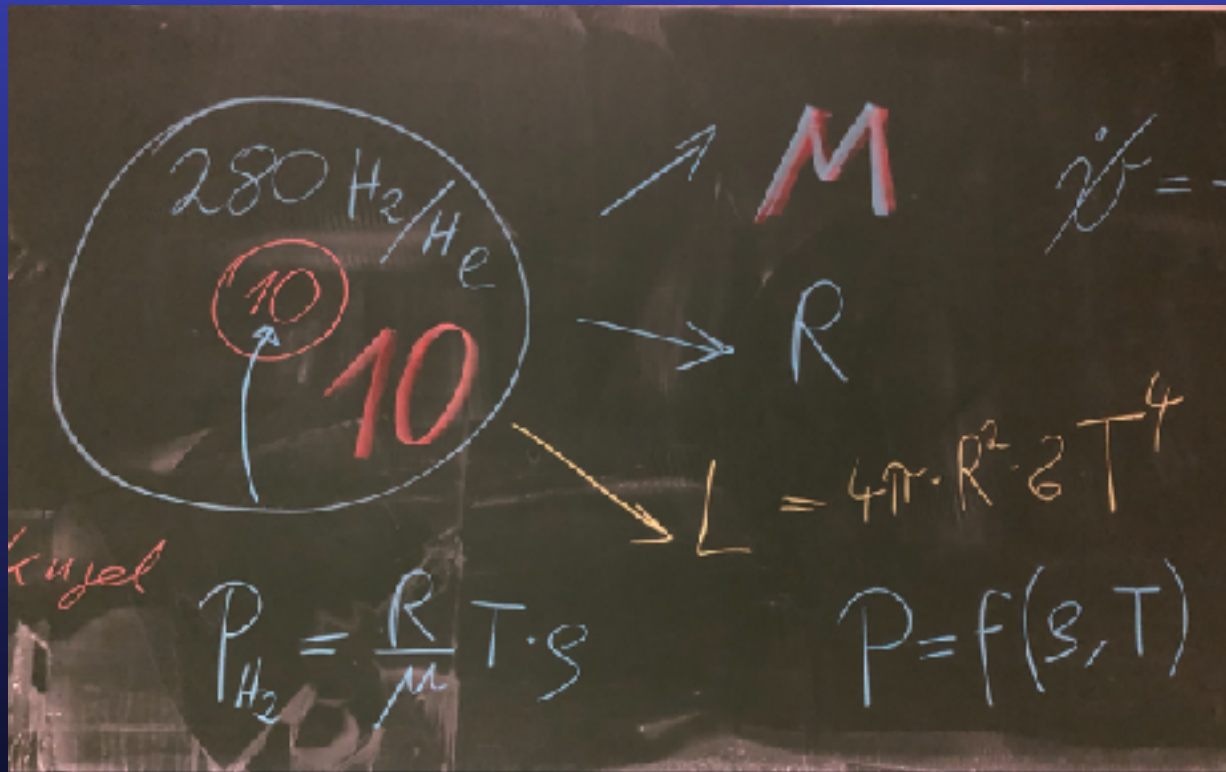
Beispiel Erdatmosphäre (Wiederholung)

$h = 10\text{km}$



Ab ~ 5 Erdmassen: Gas-Akkretion = keine stabile Atmosphäre mehr möglich.

Aus Masse, Grösse und Leuchtkraft an der Oberfläche können wir Jupiters innere Struktur bestimmen:



Indirekter Hinweis auf eine Kern (10 M_{Erde}) im Innern von Jupiter.

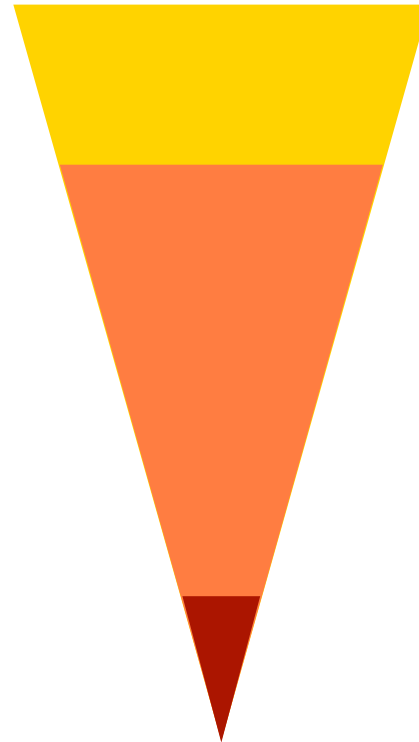
Innere Struktur von Jupiter

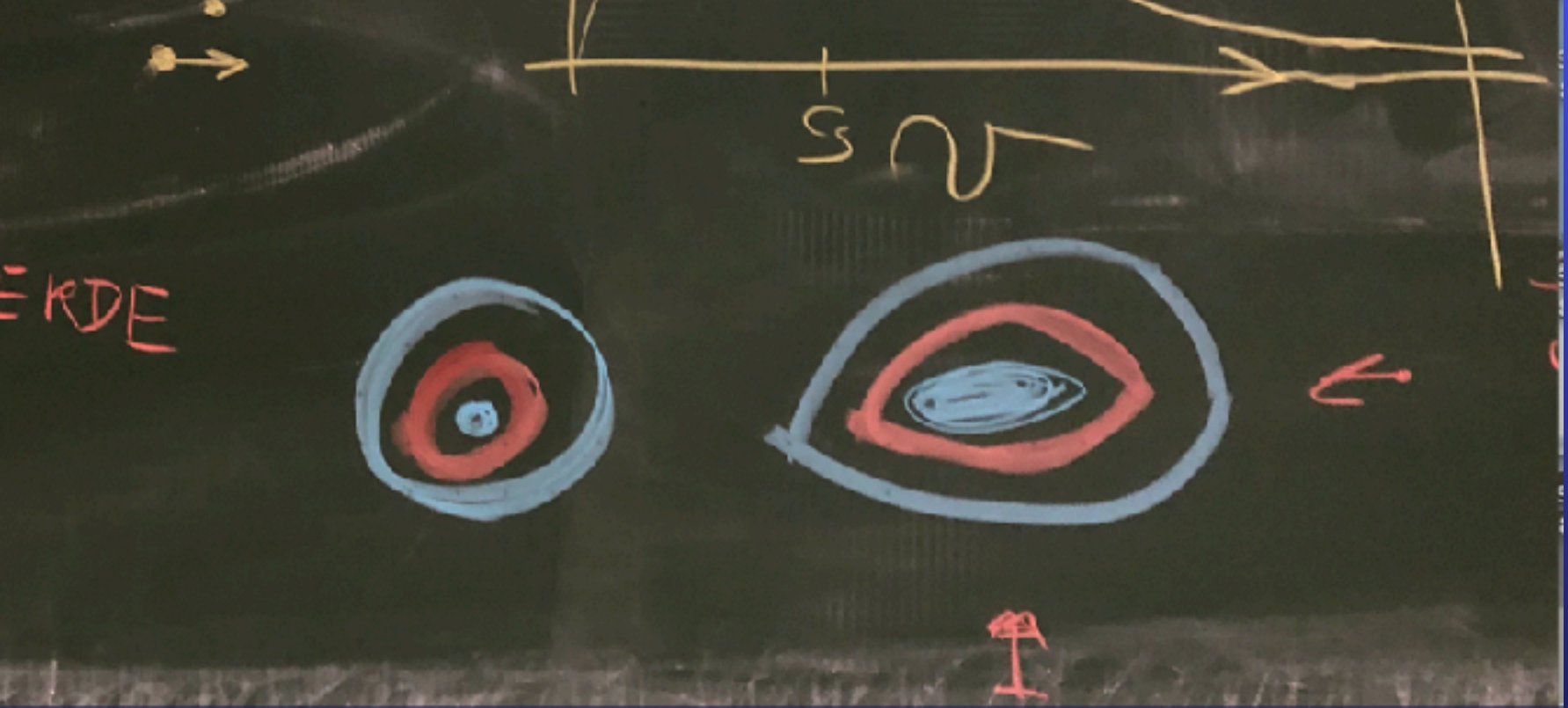
$$\frac{\partial P}{\partial r} = -\rho g,$$

$$\frac{\partial T}{\partial r} = \frac{\partial P}{\partial r} \frac{T}{P} \nabla_T,$$

$$\frac{\partial m}{\partial r} = 4\pi r^2 \rho,$$

$$\frac{\partial L}{\partial r} = 4\pi r^2 \rho \left(\dot{\epsilon} - T \frac{\partial S}{\partial t} \right),$$





**Schnell drehende Planeten flachen sich ab:
Das gilt auch für die innere Schichtung. Die
gemessene Abweichung vom Gravitationspotential
einer Kugel (gemessen an Kugelflächenfunktionen
 $J_1, J_2, J_3, J_4, \dots$) gibt dann Hinweise auf die
Schichtung, den Dichte Verlauf ρ^{\circledR}**

Jupiter's rotation & J_2

Even gravity

J_2 harmonics

J_4

J_6

J_8

J_{10}

J_{12}

J_{14}

J_{16}

} Internal structure

} Atmospheric & interior dynamics

J_0 Static (rigid body) +
Dynamic (differential rotation)

Odd gravity harmonics

J_3

J_5

J_7 axially

J_9

J_{11}

$J_{2n+1} = 0$, for an

& hemispherically symmetric planet

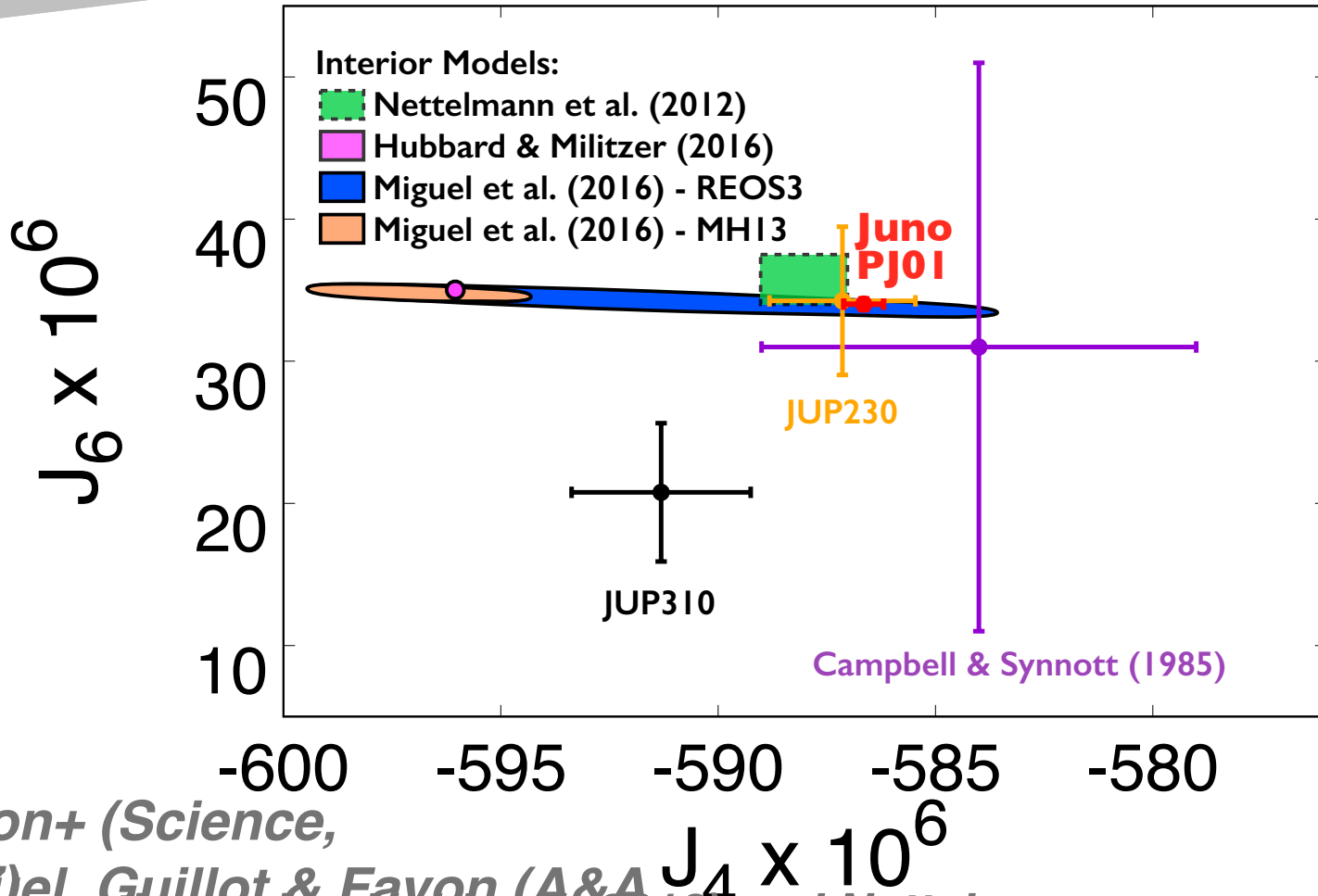
Dynamic (differential rotation)

Juno results

Nicht alle Zustandsgleichungen passen.

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Bolton+ (Science, 2017)
Guillot & Favon (A&A, 2017)
Folkner+ (GR10, 2017)
correction using Hubbard (2013) and Nettelmann (2017)

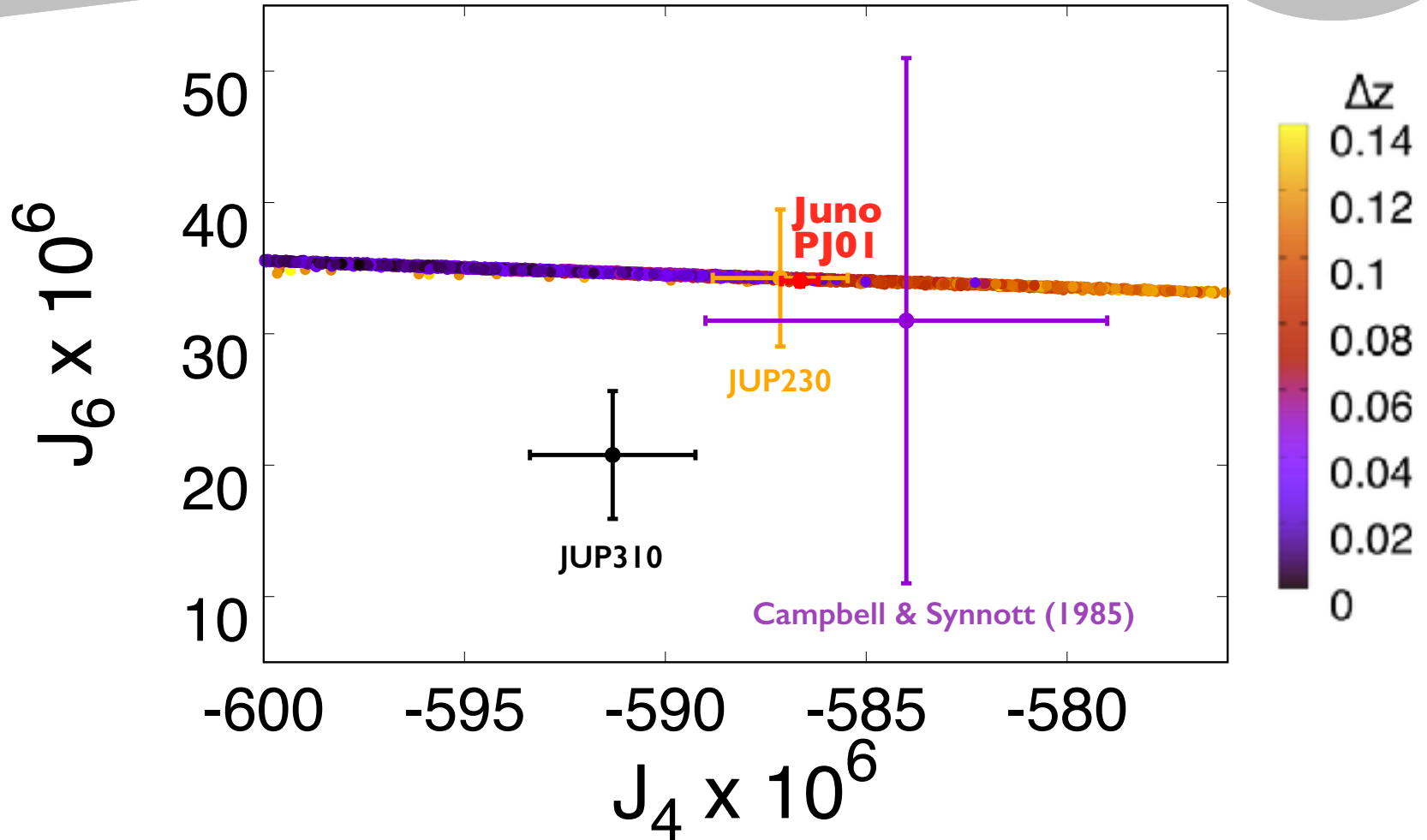


Juno results

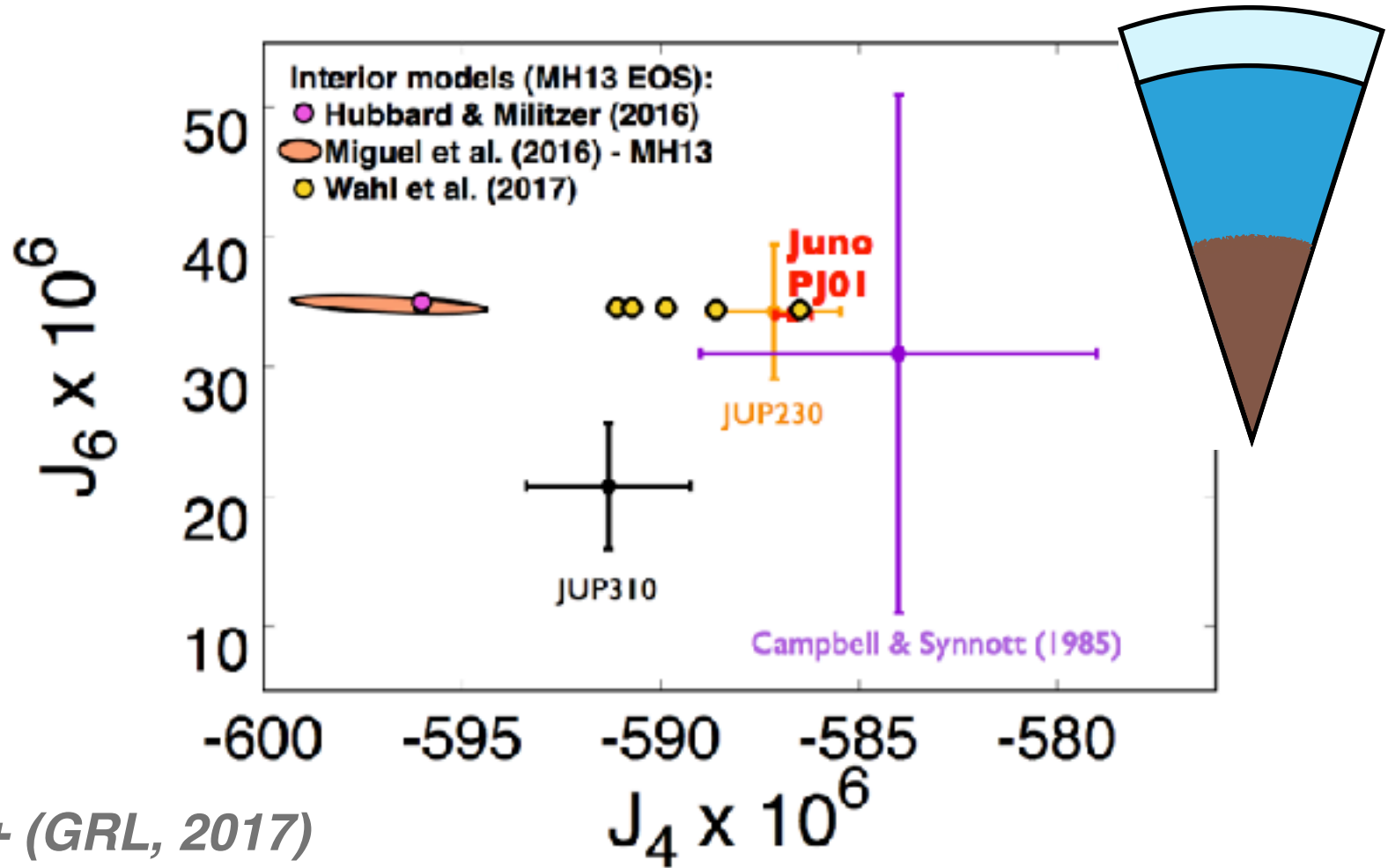
Modeling Jupiter's interior

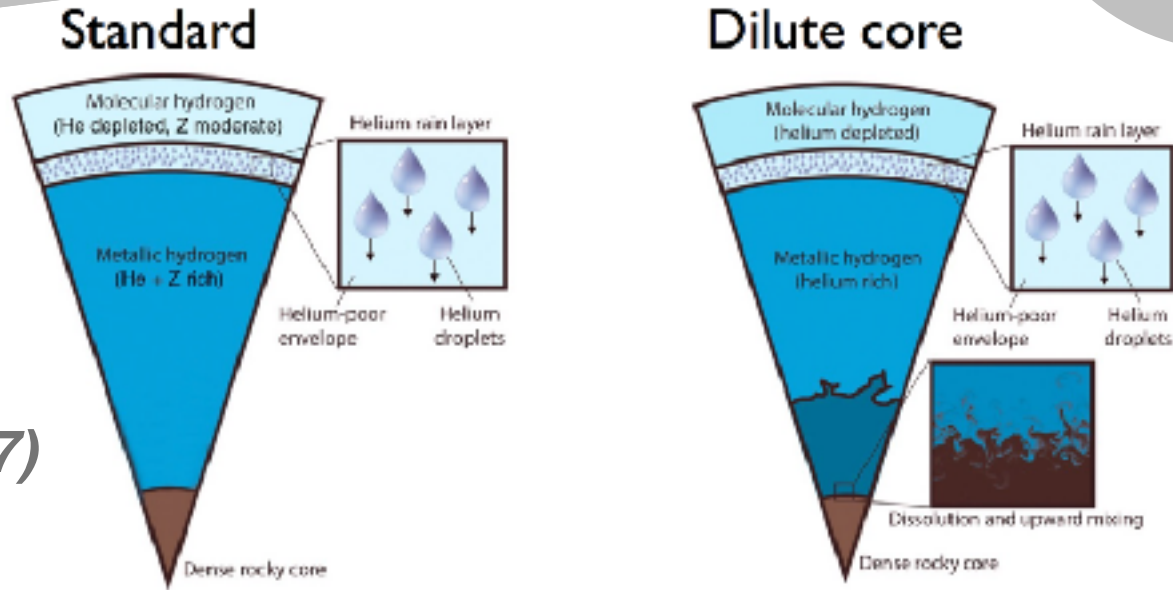
Vaniya Vignani
(MSc - Fall 2013)

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Modeling Jupiter's interior





Wahl+ (GRL, 2017)

REOS3 ✓

MHI3 ✗

REOS3 ✓

MHI3 ✓

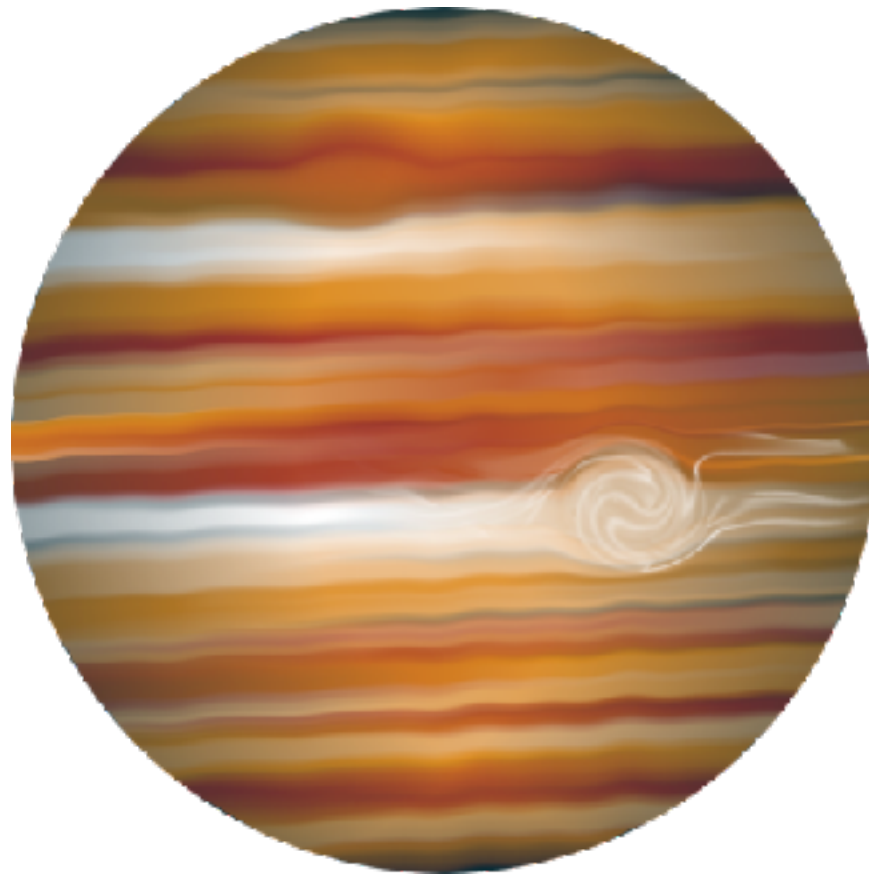
Jupiter is not homogeneous
 (Liu et al. 2015 Lozovsky et al. 2017, Helled & Stevenson 2017)

Juno results

Modeling Jupiter's interior

*Vanila Nogueira
MSc - (Jan 2013)*

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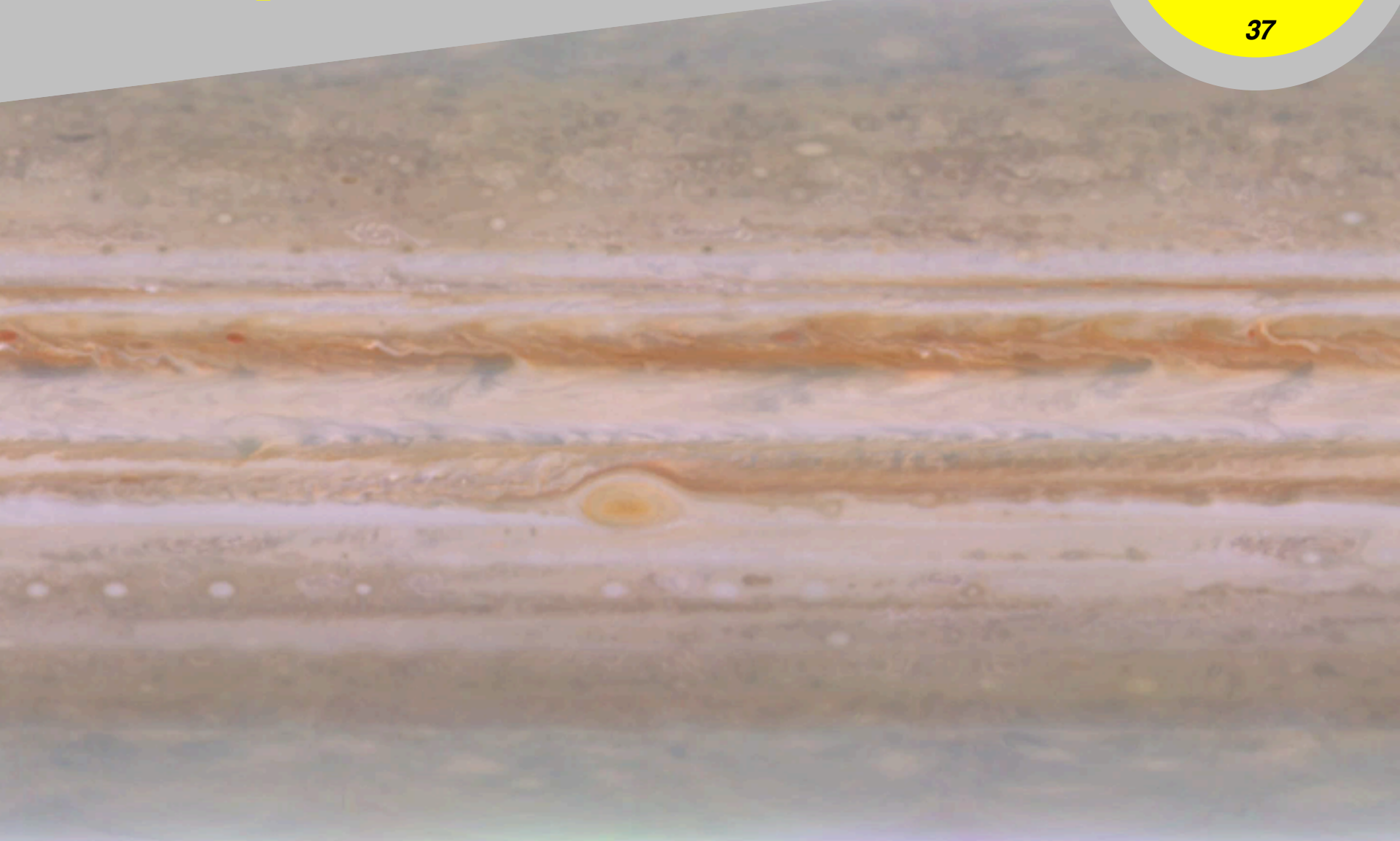
Differential rotation



Juno results

Jupiter's rotation & f

Yamila Miguel
MPA May 2018



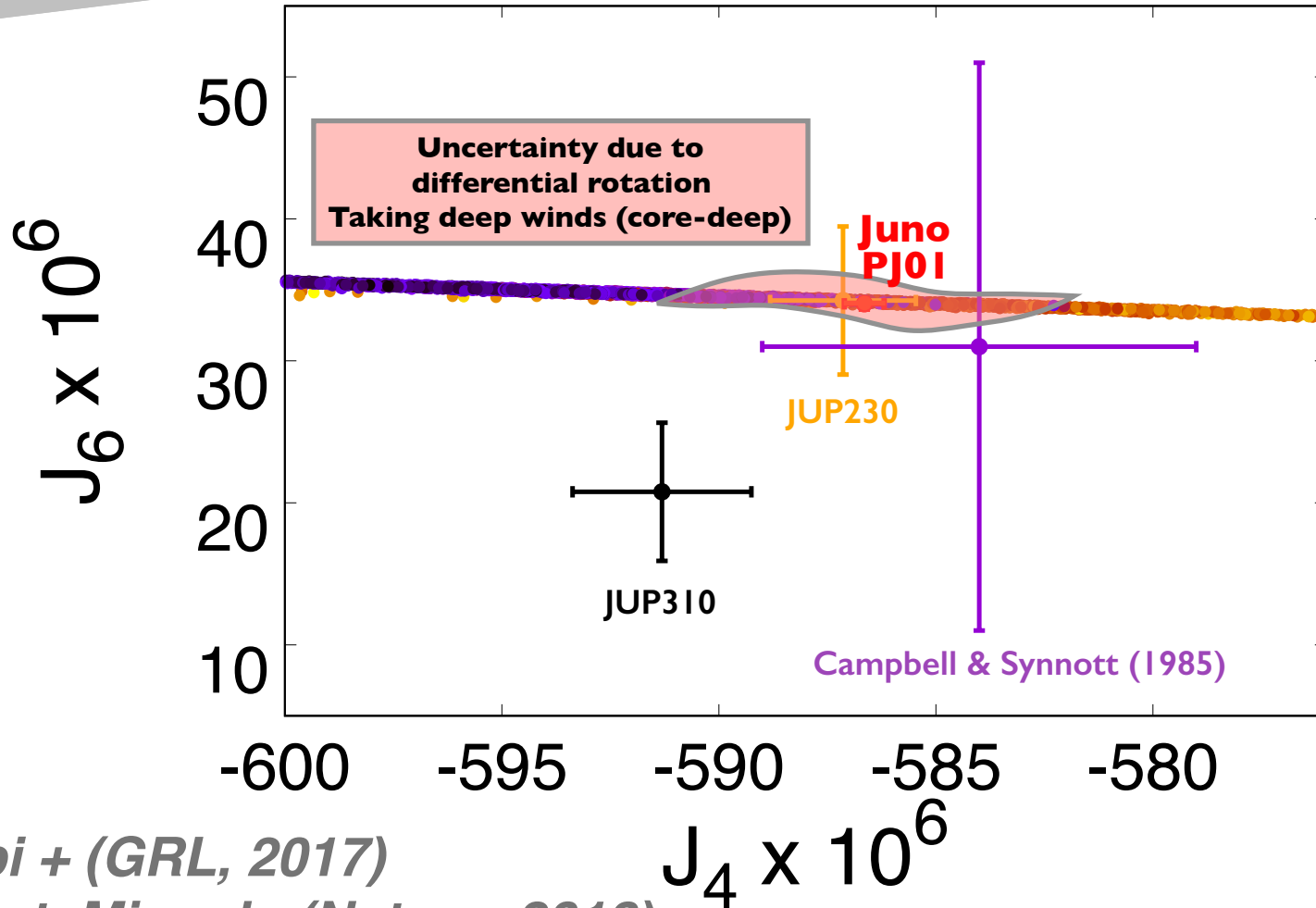


Juno results

Jupiter's rotation

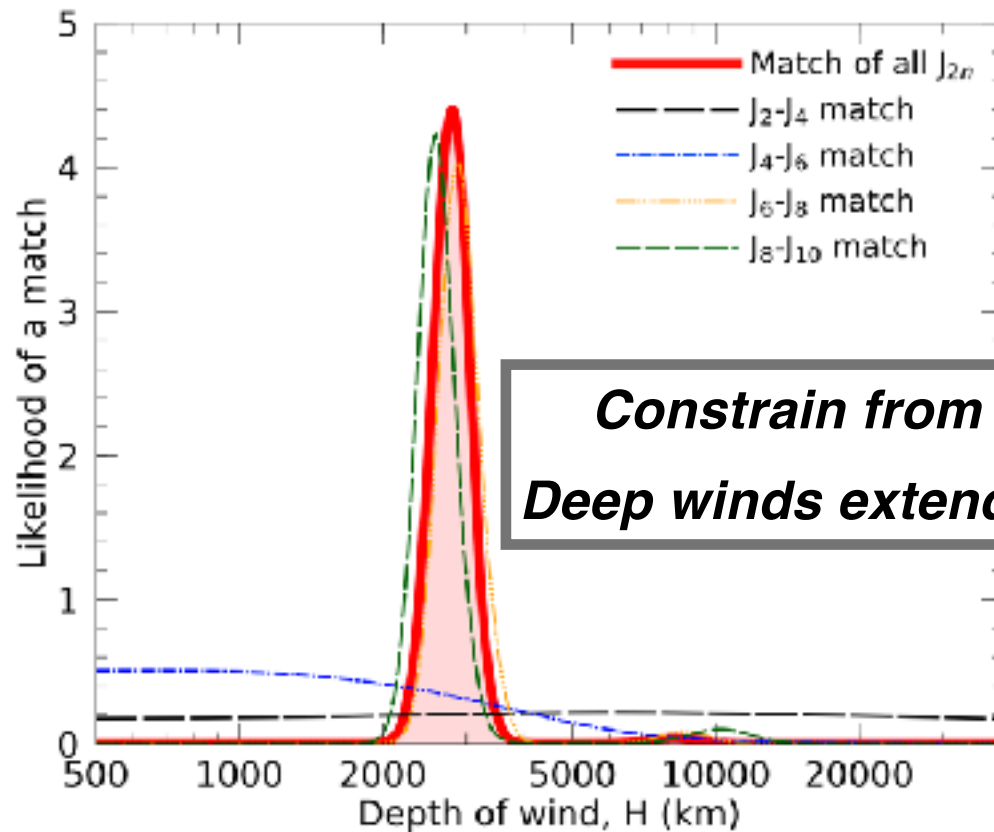
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Kaspi + (GRL, 2017)

Guillot, Miguel+ (Nature, 2018)



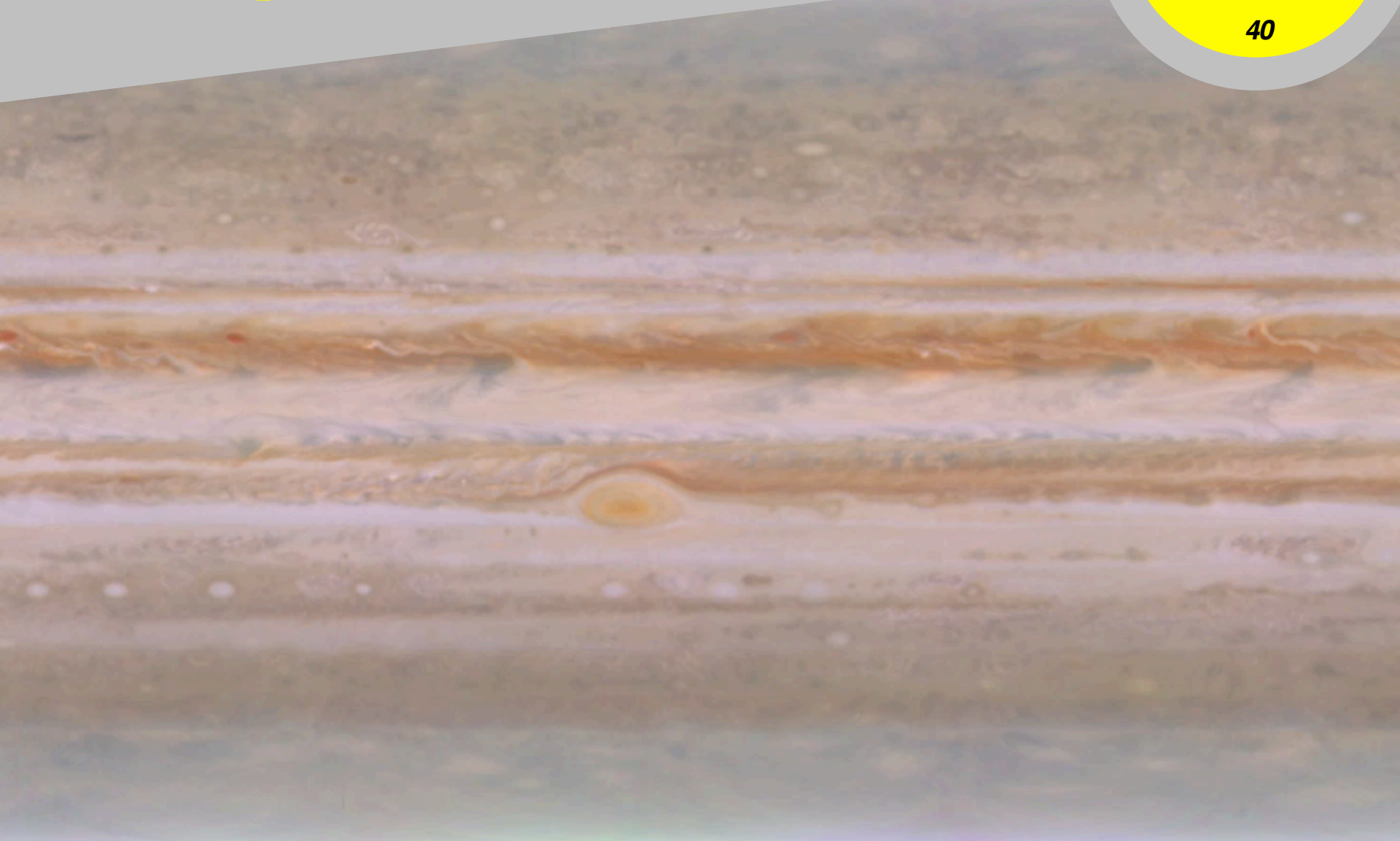
Juno results



Jupiter's rotation & f

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Jupiter's rotation & f

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